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(54) **Digital information transmission system and method.**

(57) A digital transmission system and method for coherent optical systems in which a source signal (1) is frequency modulated by digital information and caused to be incident on a birefringent medium (20). Modulation signals are produced having a polarisation which is dependent on the frequency of the source signal. The information can be regenerated by processing only one the modulation signals and thus only one need be transmitted. Further modulation signals may be transmitted to enable error checking at the receiver.

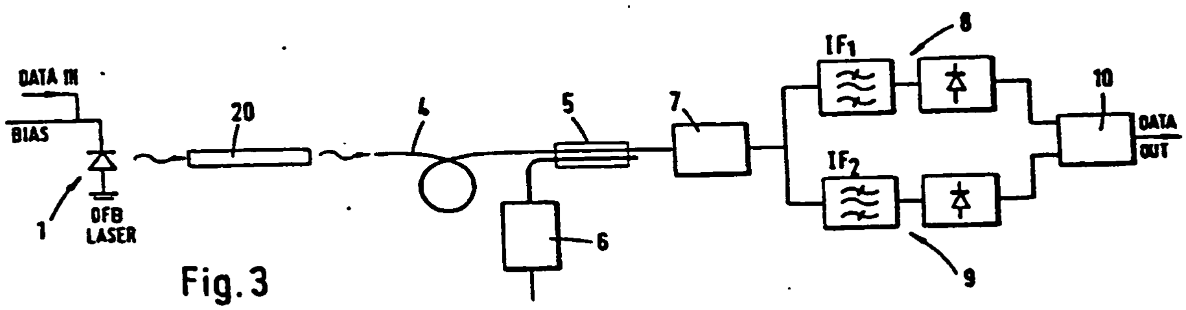

Fig.3

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DIGITAL INFORMATION TRANSMISSION SYSTEM AND METHOD

The present invention relates to the transmission of digital information in which electro-magnetic radiation is modulated in accordance with the information.

Various detection methods have been proposed in the past for demodulating the transmitted radiation including coherent detection and direct detection. Although coherent detection has major advantages over direct detection, it has the drawback of polarisation sensitivity. This problem could, in priniciple, be eliminated if a transmission medium could be developed which was polarisation holding.

In the case of optical radiation, special optical fibres have been developed which are substantially polarisation holding but these have complex structures and much higher losses (and are more expensive) when compared to standard circular symmetric monomode fibres. Furthermore, since large quantities of standard optical fibre have already been installed, are being installed, and are planned for telecommunications networks, which use polarisation insensitive equipment and direct detection, it is desirable to devise a transmission method and system which is compatible with these fibre coherent networks.

So far two schemes have been proposed that will enable coherent detection to be used with standard fibre; these are active polarisation control and polarisation diversity. The former is capable of eliminating all polarisation penalties. However, an extra opto-mechanical or electro-optic device is required in either the local oscillator or signal path at the receiver. This complicates the receiver and could also result in an insertion loss penalty. Polarisation diversity reception eliminates the need for extra optical control devices in the receiver but requires the addition of a polarising beam splitter and a second photodiode, amplifier chain and intermediate frequency (I.F.) demodulator. With polarisation diversity reception there can be up to 3dB receiver sensitivity penalty for certain combinations of input polarisation and local oscillator polarisation states when the outputs of the two I.F. demodulators are simply combined (although it may be possible toreduce this penalty to about 1dB with more complex post demodulator processing).

These two methods of overcoming polarisation problems both result in a more complex receiver which although possibly acceptable in a long distance high capacity point-to-point transmission link could introduce a significant cost penalty in a local wideband distribution scheme or LAN/MAN type application.

In accordance with the present invention there is provided a method of transmitting digital information comprising:
frequency modulating a polarised electromagnetic signal in response to said information;
causing said electromagnetic signal to be incident on a birefringent medium so as to generate modulation signals having a polarisation which corresponds to the frequency of said electromagnetic signal; and
transmitting at least one of said modulation signals.

Preferably said method further comprises detecting said information on the basis of said at least one of said modulation signals.

Preferably, instead of making use of the absolute polarisation of radiation, changes in polarisation state between adjacent bits are detected at the receiver and the absolute polarisation does not matter.

We have realised that although the output state of polarisation of a long transmission path using standard optical fibre fluctuates, it does so only slowly. For cable buried under the ground, where the temperature remains fairly stable, significant fluctuations may not occur over several hours.

The detection of the transmitted wave may be achieved in any conventional manner. Preferably, however, the detecting step comprises combining the transmitted modulated wave with a detection signal of fixed polarisation to generate a wave with an intermediate frequency, and detecting changes in phase and/or amplitude of the intermediate frequency wave to regenerate the information.

In some examples, the modulation step may comprise switching the polarisation of the wave between two values at for example 90°. Alternatively, a change in polarisation within a clock period may be achieved by ramping the polarisation between two polarisations.

Although the invention is applicable to electromagnetic radiation with a variety of wavelengths, it is particularly applicable to wavelengths in the optical domain. In this specification, the term optical is intended to refer to that part of the electromagnetic spectrum which is generally known as the visible region together with those parts of the infra-red and ultra-violet regions at each end of the visible region which are capable of being transmitted by dielectric optical waveguides such as optical fibres.

It is particularly advantageous if the method further comprises additionally modulating one or both of the phase and amplitude of the polarised electro-magnetic wave in accordance with the digital information.

This facility can be used in two ways. Firstly, double the amount of information can be sent on the transmitted wave thus doubling the transmission rate, or alternatively the digital information used to modulate the phase and/or amplitude of the polarised electro-magnetic wave may be the same information which is used to modulate the polarisation of the wave. The latter possibility provides a way of reducing the chances of error in detecting the transmitted information.

The present invention furthermore gives rise to a particularly elegant digital transmission system. The system does not require an external modulator as the source of electromagnetic radiation may be modulated directly, thus avoiding the losses associated with external modulators.

In accordance with a second aspect of the present invention there is provided a digital information transmission system comprising:
means for modulating a polarised electromagnetic signal in response to said information;
means for transmitting electromagnetic signals including a birefringent medium which is coupled to said modulating means; and
means for causing said electromagnetic signal to be incident on said birefringent medium so as to generate modulating signals having a polarisation which is dependent on the frequency of said electromagnetic signal.

Preferably said system further comprises means, coupled in use to said transmitting means, for detecting said information on the basis of at least one of said modulation signals.

Furthermore the present invention provides a simple error checking method if two modulation signals are generated in said birefringent medium and said detecting means is adapted to process said two modulation signals to generate two respective streams of digital data therefrom and compare said streams to regenerate said digital information and determine if an error has occurred in the regeneration of said information.

The source of electro-magnetic radiation may comprise for example a laser.

We believe that the invention is particularly applicable to overcoming the problem of long term polarisation stability in coherent transmission systems using monomode fibre. The invention enables considerable simplification of the detecting means such as a heterodyne receiver. This will be of benefit in future wideband distribution schemes. There may also be some scope for using the invention in optical networks that have all optical sources centrally located. In this case it may be possible to provide polarisation modulators at remote terminals fed by continuous wave light from a central laser bank.

A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 illustrates schematically one example of a transmission system;

Figure 2 illustrates the receiver of Figure 1 in more detail;

Figure 3 illustrates a preferred embodiment of a transmission system in accordance with the present invention;

Figure 4 illustrates graphically a detection method; and

Figures 5 and 6 illustrate the waveforms of input signals, local oscillator signals, and IF signals in two different examples.

The system shown in Figure 1 comprises a semiconductor laser 1 which generates a linearly polarised beam of optical radiation. The beam is fed to a polarisation modulator 2 of conventional form which is controlled via a data input 3. At successive clock periods, data is applied to the modulator 2 which causes either a change or no change in the polarisation of the incoming beam. For example, a binary digit "1" may cause a 90° switch in polarisation whereas a binary digit "0" will cause no change. The modulated radiation is then fed into a conventional monomode optical fibre 4 defining a transmission path.

At a receiving station, the optical fibre 4 is connected to an optical coupler 5 having a second input connected to a local oscillator 6 constituted by a semiconductor laser which generates circularly polarised optical radiation. The optical coupler 5 combines the incoming modulated optical signal with the local oscillator signal and the resultant IF signal is fed to a detector 7.

Information is contained in both the differential phase, ie. the change in phase between clock periods, and the differential amplitude of the IF signal, that is the change in amplitude between clock periods.

The relative magnitude of the demodulated phase signal to the demodulated amplitude signal will depend on the relationship of the received state of polarisation to that of the local oscillator polarisation. For certain combinations of input signal to local oscillator polarisation there will be no useful amplitude information. Take, for instance, the case when the input polarisation is switching between two linear orthogonal states (Figure 5A) and the local oscillator is circular (Figure 5B). With this combination although the IF amplitude will remain constant the IF phase will switch in sympathy with the input signal's polarisation (Figure 5C). In constrast, consider the case, again with a circular local oscillator (Figure 6B), where the input signal is switching between right circular and left circular

(Figure 6A). This time the IF envelope switches completely (Figure 6C). Therefore to determine that a polarisation change has taken place it is necessary to process both the demodulated differential phase and envelope signals together. To give optimum performance in some cases it may better not to represent symbols by step changes in polarisation states but by some other function; for example a polarisation ramp.

The detector 7 which includes a filter generates an output signal which is fed in parallel to a differential phase demodulator 8 and a differential amplitude demodulator 9. The output signals from these demodulators 8, 9 are fed to a micro-processor 10 which provides an output signal representing the original data. The micro-processor 10 could select between the signals from the phase demodulator 8 and amplitude demodulator 9 the signal with the largest magnitude or it could add the two signals to produce a resultant signal.

Figure 2 illustrates one way in which the demodulators 8,9 could be implemented. The detector 7 includes a sensor 11 such as a photodiode whose output is fed to an amplifier 12 and then to a filter 13 and a further amplifier 14. The amplitude demodulator 9 is constituted by a conventional envelope detector 15 whose output is split and fed in parallel to the inverting and non-inverting inputs of a differential amplifier 16. The path length to the non-inverting input is longer than that to the inverting input so that a single clock period (or bit period) delay is applied to that bit enabling comparison of signal levels between adjacent bits to take place. Ina similar manner the phase change between adjacent clock periods or bits is determined by splitting the path from the amplifier 14 into two 17, 18, delaying one path 18 by a single bit period, and multiplying the two signals in a double balanced modulator 19.

The micro-processor 10 determines what weighting should be given to each of the two demodulated signals. In the simplest case it may be possible to take the signal which has the largest peak-to-peak level.

A transmission system which is in accordance with the present invention is illustrated in Figure 3. In this system the frequency of the optical radiation generated by the semiconductor laser 1 is modulated directly by the digital data. This frequency modulated radiation, of fixed polarisation, is fed to a short length of high birefringence fibre 20. Preferably, the frequency modulated beam is launched at ū/4 to the birefringent axis of the fibre 20. The output polarisation from this short length of fibre 20 will be dependant on the optical frequency of the source and can therefore be modulated as the laser frequency is modulated. The beam output from the fibre 20 is then coupled to the main optical fibre 4.

Frequency modulation of a semiconductor laser can be achieved directly by control of injection current or by acoustic wave interaction. In the simple case of a laser directly frequency shift keyed between f_1 and f_2 (where the difference between these optical frequencies is much greater than the data rate) it is only necessary to demodulate just one of the two frequencies to determine the symbol transmitted; this single filter detection of FSK gives the same performance as ASK. If it is now arranged that the frequency shift is sufficient for the two signals to have orthogonal polarisations we now have a choice of two signals that could be detected at the distant receiver and either signal containing the transmitted information. The local oscillator frequency at the receiver could be tuned to whichever signal presented the best polarisation match.

Moreover, by careful selection of the IF frequency with respect to $f_1 - f_2$ it may be possible to site the signal associated with the orthogonal polarisation state near the image band of the detected signal. Therefore under this condition where the local oscillator frequency is positioned just off centre of $(f_1 - f_2)/2$, as shown in Figure 4. Either signal would automatically appear in the receiver IF bandwidth, individually or together depending on the received polarisation state. In this case polarisation diversity may be possible without retuning. the frequency of the receiver local oscillator laser.

Claims

1. A method of transmitting digital information comprising:
frequency modulating a polarised electromagnetic signal in response to said information;
causing said electromagnetic signal to be incident on a birefringent medium so as to generate modulation signals having a polarisation which corresponds to the frequency of said electromagnetic signal; and
transmitting at least one of said modulation signals.

2. A method as claimed in claim 1, further comprising detecting said information on the basis of said at least one of said modulation signals.

3. A method as claimed in claim 2, wherein said detecting step includes monitoring changes in said at least one of said modulation signals to regenerate said information.

4. A method as claimed in claim 3, wherein said information is detected on the basis of the level of said at least one of said modulation signals.

5. A method as claimed in claim 4, wherein two modulation signals are generated and said method further comprises transmitting and processing said two modulation signals to generate two respective streams of digital data therefrom, and comparing said streams to regenerate said digital information and determine if an error has occurred in the regeneration of said digital information.

6. A method as claimed in claim 5, wherein said electromagnetic signal is caused to be incident on said birefringent medium at Ü/4 to the axis of said medium.

7. A method as claimed in claim 6, wherein said detecting step includes causing said two modulation signals to interfere with a polarised local oscillator signal of predetermined frequency so as to generate two respective intermediate frequency signals, both having frequencies which fall within an intermediate frequency band of means for performing said detecting step.

8. A method as claimed in any one of the preceding claims, further comprising modulating the amplitude and/or phase of said electromagnetic signal in response to digital information.

9. A digital information transmission system comprising means for modulating a polarised electromagnetic signal in response to said information;
means for transmitting electromagnetic signals including a birefringent medium which is coupled to said modulating means;
means for causing said electromagnetic signal to be incident on said birefringent medium so as to generate modulation signals having and polarisation which is dependent on the frequency of said electromagnetic signal.

10. A system as claimed in claim 9, further comprising means, coupled in use to said transmitting means, for detecting said information on the basis of at least one of said modulation signals.

11. A system as claimed in claim 10, wherein said detecting means monitors changes in said at least one of said modulation signals to regenerate said information.

12. A system as claimed in claims 10 or 11, wherein said detecting means detects said information on the basis of the level of said at least one of said modulation signals.

13. A system as claimed in claim 12, wherein two modulation signals are generated in said birefringent medium and said detecting means is adapted to process said two modulation signals to generate two respective streams of digital data therefrom and compare said streams to regenerate said digital information and determine if an error has occurred in the regeneration of said information.

14. A system as claimed in claim 13, wherein said detecting means causes said two modulation signals to interfere with a polarised local oscillator signal of predetermined frequency so as to generate two respective intermediate frequency signals, both having frequencies which fall within an intermediate frequency band of said detecting means.

15. A system as claimed in claim 14, wherein said electromagnetic signal is caused to be incident on said birefringent medium at Ü/4 to the axis of said medium.

16. A system as claimed in claim 15, wherein said detecting means includes
a local source for generating said local signal;
a main detector including electromagnetic to electrical signal conversion means and a filter having said intermediate frequency band;
a coupler for coupling said transmitting means and said local source to said main detector;
subsidiary detectors connected to said main detector which generate said digital data from said modulation signals, respectively; and
processing means for generating said digital information in response to receiving said digital data from said subsidiary detectors.

17. A system as claimed in claim 16, further comprising a broadband source for generating said polarised electromagnetic signal, said modulating means being connected to said broadband source.

18.A system as claimed in any one of claims 9 to 17, wherein said modulating means is adapted to modulate the amplitude and/or phase of said electomagnetic signal in response to digital information.

19. A system as claimed in claim 18, wherein said transmitting means further includes an electromagnetic waveguide coupled to said birefringent medium.

20. A method as claimed in any one of claims 1 to 8, wherein said electromagnetic and modulation signals are optical signals.

21. A system as claimed in any one of claims 9 to 19, wherein said electromagnetic and modulation signals are optical signals.

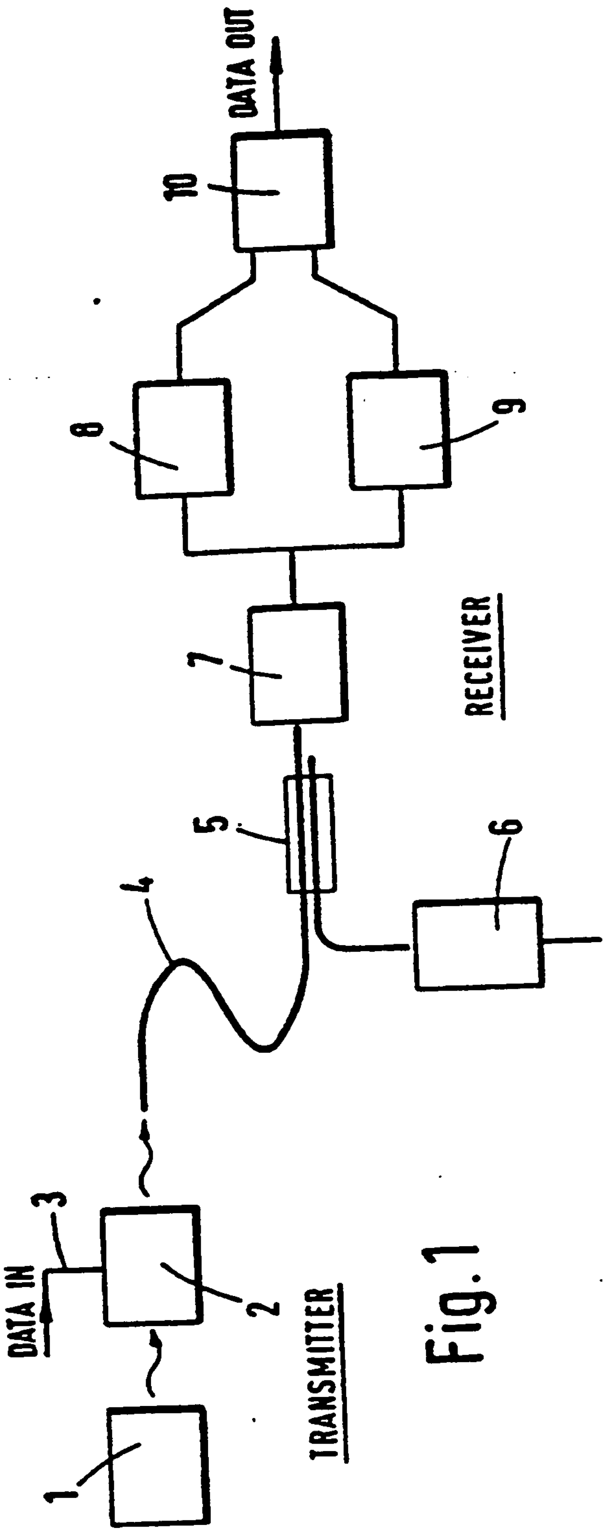
DATA IN
3
2
1
4
5
6
7
8
9
10
DATA OUT
TRANSMITTER
RECEIVER

Fig.1

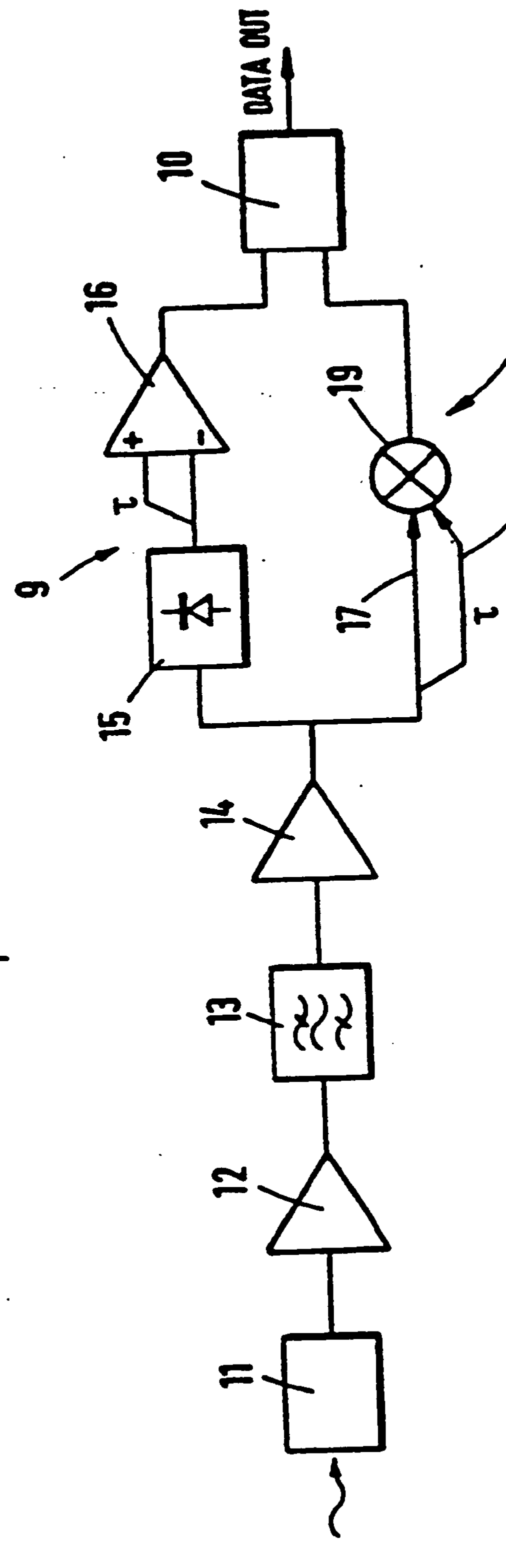
11
12
13
14
15
9
16
τ
17
18
19
8
10
DATA OUT

Fig.2

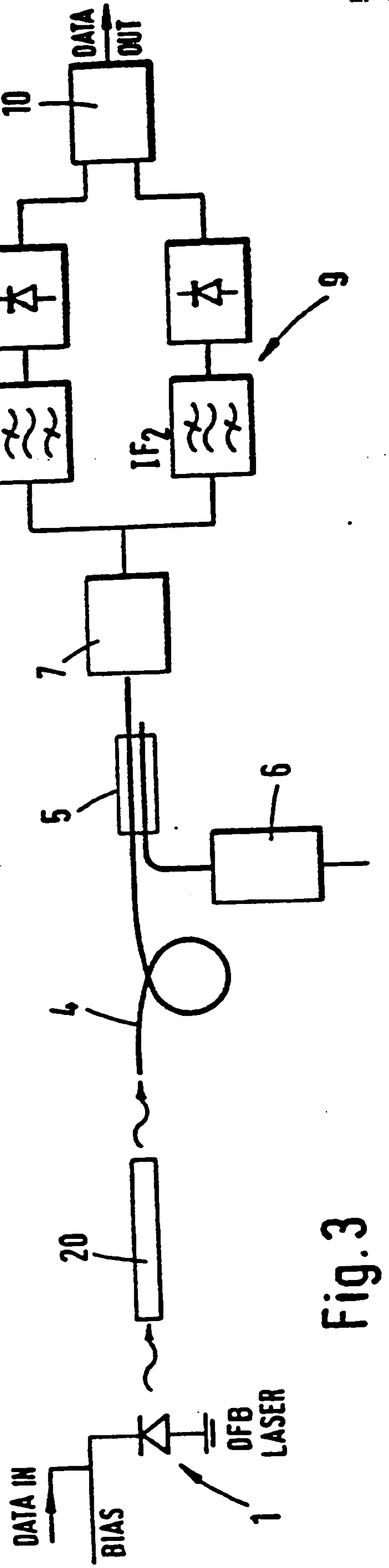
DATA IN
BIAS
1
DFB LASER
20
4
5
6
7
IF1
IF2
8
9
10
DATA OUT

Fig.3

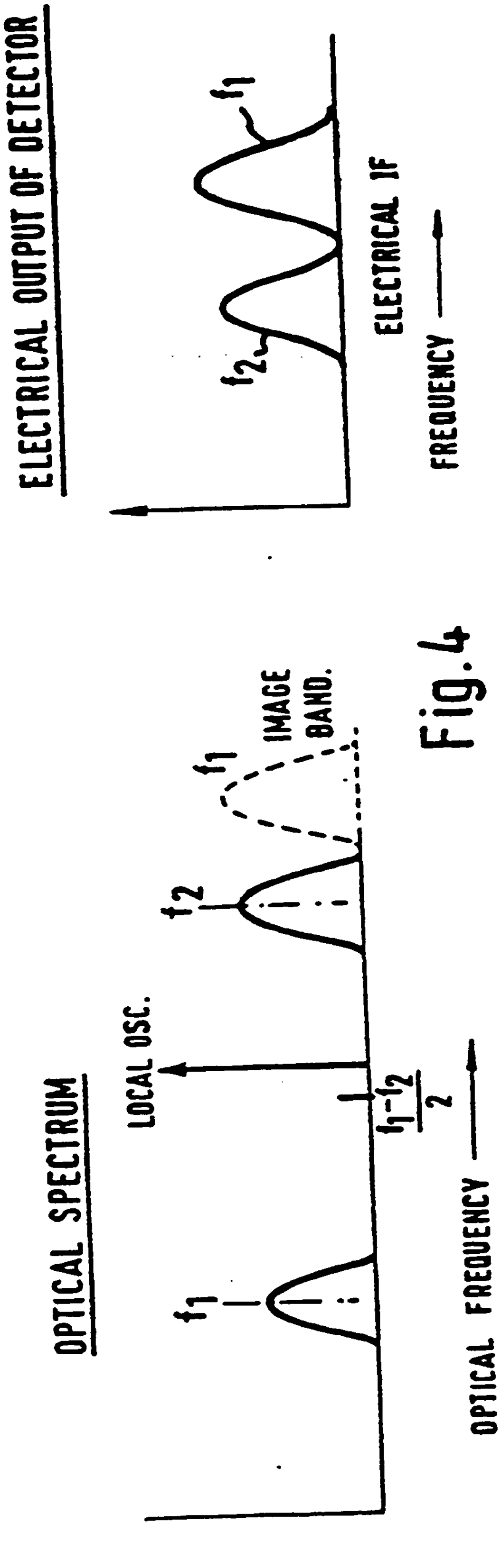
ELECTRICAL OUTPUT OF DETECTOR
f2
f1
ELECTRICAL IF
FREQUENCY
OPTICAL SPECTRUM
LOCAL OSC.
f1
f2
f1
IMAGE BAND.
(f1-f2)/2
OPTICAL FREQUENCY

Fig.4

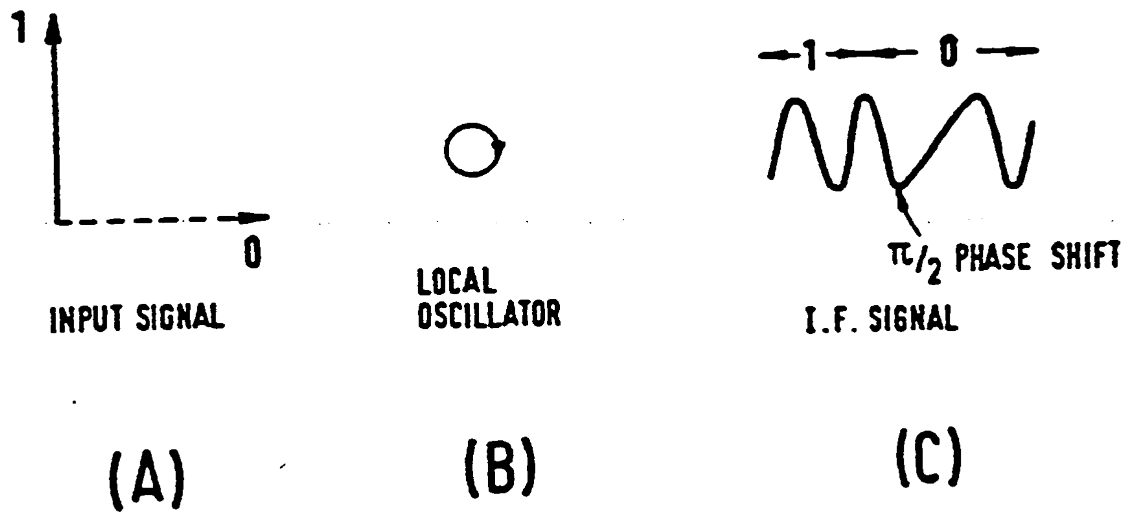
1
0
INPUT SIGNAL
LOCAL
OSCILLATOR
1
0
π/2 PHASE SHIFT
I.F. SIGNAL
(A)
(B)
(C)

Fig.5

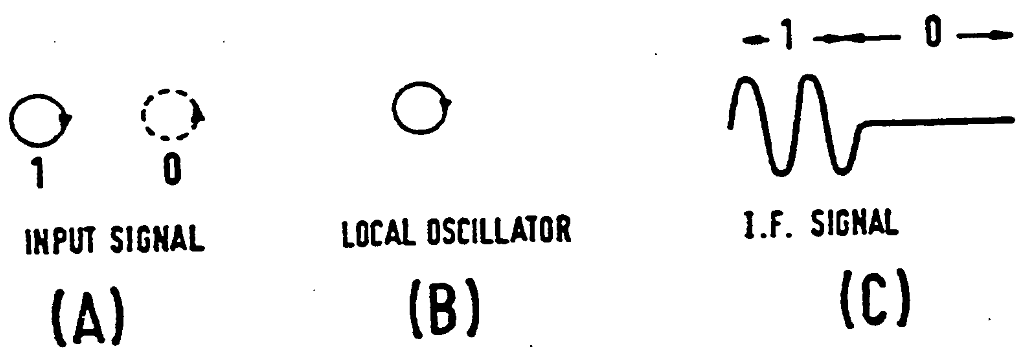
1
0
INPUT SIGNAL
LOCAL OSCILLATOR
1
0
I.F. SIGNAL
(A)
(B)
(C)

FIG.6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 89 10 3280

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X A	US-A-3 457 414 (RAGEN) * Column 1, lines 10-17,30-33; column 2, lines 10-38; column 4, lines 12-19 * ---	1,2,4,5,8-10,12,13,20,21 16-18	H 04 B 9/00 H 04 B 14/00
A	US-A-3 214 590 (SCHACHTMAN) * Column 2, lines 48-50,58-62; column 3, lines 33-37 * ---	1,19	
A	US-A-3 284 632 (NIBLACK) * Column 2, lines 65-69 * ---	1,6,9,15	
A	US-A-3 415 995 (KERR) * Figure 2; column 2, lines 60-64; column 3, lines 28-38 * ---	1,6,7,9,14,15	
A	EP-A-0 138 584 (SEIKO) * Claim 1 * ---	3,11	
A	US-A-4 464 756 (TROMBORG) * Column 3, lines 12-23 * -----	5,13	TECHNICAL FIELDS SEARCHED (Int. Cl.4) H 04 B H 04 L H 04 J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20-04-1989	GEISLER J.A.R.

CATEGORY OF CITED DOCUMENTS

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